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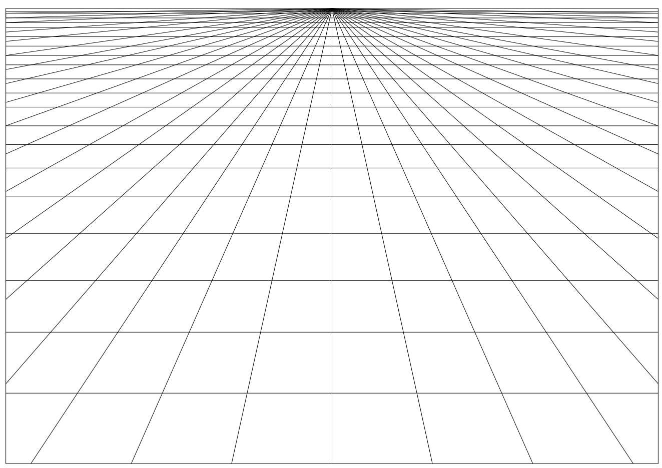

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From Waste to Wheel
– Development and diffusion of second generation biofuels in Norway

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Abstract

This paper seeks to contribute to greater understanding of second generation (2G) biofuels and related processes that drive or inhibit further development and diffusion. Three Norwegian firms that are in the process of developing technologies to produce 2G biofuels are studied, focusing on identifying some of the main challenges towards commercialization. The firms are seen in a systemic perspective as part of an evolving technological system (TIS) related to 2G biofuels. The systemic perspective is used in order to illustrate the complex nature of technological development, including the reciprocal relationship between society and technology. The emerging industry is currently in a formative phase and is characterized by many entrants, uncertainty in terms of policies, competing designs and technological heterogeneity. The paper focuses on what type of challenges that have to be overcome at this stage, and furthermore the influence of various institutions and organizations upon development and diffusion. The role of major actors within the Norwegian national system is thus focused upon, including research organizations. Several historical linkages and trajectories are also illustrated, while also indicating central policy issues. The paper concludes by discussing some aspects for further research.

Keywords: Innovation, technological innovation systems, policy, 2G biofuels,

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Arne Willy Hortman

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Contents

Chapter 1

1.0 Introduction:

This thesis focuses on three Norwegian firms that are in the process of developing technologies to produce second generation (2G) biofuels. Firms are here considered key actors in an emerging technological innovation system (TIS), where innovation is considered to take place in a co-evolution between actors, organizations and institutions. Within this type of systemic perspective not only the competence of single innovating firms are important, but also the competence of suppliers, users, knowledge providers and policy makers (Fagerberg et al. 2005). Innovation is today widely considered central to economic growth (see e.g. Edquist et al., 2001), but technological development is also increasingly being considered as an instrument to solve other social challenges. This notion is also becoming more integrated in policymaking, and especially in relation with the development of alternative energy technologies. The objective of the thesis is to increase the understanding of the evolving technological system related to the development and diffusion of 2G biofuels, and in particular the challenges for successful commercialization of related technologies. In addition, it is the author's hope that this paper also will contribute to valuable insight for development of future policies related to sustainable innovation.

1.1 Contextual framework

The energy sector has in recent years been subject to greater awareness of the environmental consequences of the existing fossil-based energy system (Jacobsson and Johnson 1998). As a response to awareness of human- induced climate change and the potential end of fossil fuels, a demand for "green" energy has emerged, leading to an increased focus on development of renewable energy technologies (Ibid). Within the Norwegian context, recent reports have argued that the production of renewable energy must increase if the rising demand is to be met nationally (See e.g. Climate Cure 2020, 2010).[1] Biological material has for a long time been considered a promising renewable energy source, and several technological solutions to exploit this energy have been well-known since the beginning of the industrial era. While biological material may be used for several purposes, biofuels have been considered amongst the most promising alternatives to replace fossil fuels within the transportation sector. According to Statistics Norway (SSB**)**, road traffic in 2006 accounted for about 28 percent of the national emissions of the three most important greenhouse gasses; carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O).[2] Road traffic is also by far the most important reason for the increase in the total emissions of greenhouse gases.**[3]** The burning of fossil fuels constitutes the primary source of emissions, and diffusion of biofuels is therefore considered crucial in order to reduce emissions within the transportation sector. This view is also echoed by Climate Cure 2020:

[1] Climate Cure 2020 is a report commissioned by the Norwegian Ministry of Environment focusing on measures and

[2] SSB: http://www.ssb.no/emner/01/04/10/klimagassr

[3] Ibid.

"The greatest emissions reductions can be achieved by increasing the consumption of biofuels and phasing in more vehicles with lower emissions per driven kilometre (electrification, increased efficiency)" (Climate Cure 2020, 2010)

Despite increasing demand and available products and technologies, biofuels only accounted for around 4% of the total fuel consumption in Norway in 2008 (96% of this was biodiesel mixed with regular diesel).[4] The reasons for the relatively low diffusion of biofuels may be complex, but biofuels have been subject to controversy. Technologies to produce biofuels based on potential food resources, often collectively labelled 'first generation' (1G), have particularly been subject to debate. Central issues of this debate have been the effect biofuels have had on food prices and conservation of bio-diversity. In addition, the question has been raised whether further diffusion of biofuels in fact would contribute to reduce the emissions of greenhouse gasses sufficiently? The use of fertilizer and other factors that cause emissions during the production and transportation of biofuels have contributed to further uncertainty around this question. The firms represented in this paper are developing technologies for the production of second generation (2G) biofuels, which are not in conflict with food production. As these firms and related technologies are shaped by the social context in which they operate, the various types of biofuels should not automatically be seen as totally separate entities. The technological system related to 2G biofuels is complex and influenced by many factors where social factors must be considered, including questions surrounding long-term environmental consequences,

[4] SSB: http://www.ssb.no/vis/magasinet/miljo/art-2009-07-03-01.html

in relation to development and diffusion of these technologies. In the literature on industry and life cycles it is usually possible to identify two main phases in the evolution of an industry; a formative period and one of market expansion (Jacobsson and Bergek 2003). Industries in the formative phase are usually characterized by competing designs, many entrants, small markets and high uncertainty in terms of technologies, markets or policies (Ibid). The emerging 2G biofuel technological system (TIS) is characterized by technological heterogeneity through the existence of several different products and production processes. A growing number of global entrants, technologies under development, uncertainties linked with policies and competing designs indicates that the TIS related to 2G biofuels in Norway is currently in a formative phase. From a firm's perspective, the many uncertainties in with this phase contribute to great risks, but there is also potential in being an early mover within an emerging industry. The firms represented in this paper are not only dependent on successful development of "working" technologies, but also on a number of social factors that influence further diffusion of 2G biofuels, and thus successful commercialization and innovation.

1.2 Theoretical framework

Technology is influenced by multiple factors, and is shaped by the social climate in which it is developed. Systemic theories of innovation echo this view and a systemic approach may be useful in this sense. Charles Edquist defines the system of innovation as: *"…all important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations"* (Edquist 2005). Systemic theories on innovation and related approaches will be elaborated upon as a part of the analytical framework in chapter four. The understanding that innovation and technological development are results of complex processes where institutions and organizations act in correlation, is however an important foundation for this paper. A central goal for the represented firms is to develop “working” technologies and to successfully commercialize these. When studying technology, Bruno Latour (1987) has encouraged to “open the black boxes” in order to better understand the social factors that influence technological development. Influenced by Latour, the represented technologies are given increased attention in order to achieve an understanding of these, and also to potentially reveal central challenges, including issues that are linked directly with the production process. Though linked with the production process or other areas, these challenges must also be considered in their social context. By focusing on the technology, social patterns may become visible.

1.3 Research question and focus of the paper:

This paper analyses three Norwegian firms that are currently developing technology to produce biofuels based on non-food feedstock, commonly labelled 'second generation' (2G). The firms are here considered key developers of technology, but are seen in the context of an emerging technological innovation system related to 2G biofuels. The aim of this paper can roughly be described as three main goals:

- Develop a general understanding of 2G biofuels as being developed by represented firms.
- Contribute to increased knowledge related to what influences the development of 2G biofuels.
- Contribute to increased knowledge regarding the main challenges to diffusion and commercialization of 2G biofuels.

I employ a systemic perspective in order to embrace a number of factors that influence the development and diffusion of these technologies and to greater illustrate the context in which the companies operate. I consider the firms to be part of an evolving technological system related to 2G biofuels. A technological innovation system (TIS) should be considered a social network consisting of many actors (including various organizations and institutions) related to a specific type of technology.[5] While this paper focuses on Norwegian actors, the energy sector is characterized by cross-border cooperation, and the often complex processes that shape innovation are not necessarily restricted by national borders. The objective of this paper is to

[5] This will be further explained in chapter 4: Analytical framework

gain a greater understanding of this emerging technological system, and especially how the represented firms are able to establish themselves with new technologies within a new and competitive industry focusing on challenges for further commercialization. With this background I have developed the following research questions:

a) *What are the main characteristics of 2G biofuels?*

b) *How has organizations and institutions influenced development of the represented technologies?*

c) *What are considered the main challenges for diffusion and commercialization of 2G biofuels?*

Chapter 2

2.0 Methodology

This chapter accounts for the selection of research strategy and the methodological choices that have been made during the work with this thesis. Strengths and weaknesses of the research strategy are also discussed, while key sources and informants are presented towards the end of the chapter.

2.1 Research Strategy

An important aspect with all research is to decide which research strategy to choose. This is of course closely related to want one wants to study, and what questions one wants to answer. On the basis of my research questions, I have chosen a case study approach. Case study research has long traditions within STS as well as within social sciences in general. As a research strategy it is used in many situations to contribute to our knowledge of complex social phenomena (Yin 2003). The primary units of analysis are the technologies to produce 2G biofuels being developed by the represented firms. The decision to focus on the technologies is partly influenced by Bruno Latour's encouragement to "open the black boxes" of technological development (Latour, 1987). The firms and their technologies must however at this stage be considered as interconnected. Rosenberg and Kline (1986) are amongst those who have pointed out limitations of what is often labelled "black-box approach". For instance, as they point out, innovations will often generate benefits far from the industries in which they originated, which might then be overlooked (Ibid). At the same time, it is difficult to separate the technologies from their context, and nor is this desirable. The technological development related to 2G biofuels takes place within a complex environment consisting of a number of actors and social influences. The framework of a technological innovation system is therefore useful in order to develop an understanding of the complex system related to 2G biofuels. There are a number of ways one might gain further understanding of technological innovation systems, and several scholars have suggested methods for analysis and assessment of systems (see e.g. Bergek et al., 2008). There has also been written theses on 2G biofuels in Norway based partly on these methods (see e.g. Blomberg, 2008). I have chosen to focus my enquiry on the firm level in order to gain more knowledge within this specific area. By having a main focus on three firms and their technologies I hope to gain knowledge that otherwise might have been overlooked. This raises of course questions to the validity and reliability of the thesis, which will be addressed shortly. My aim with this thesis is not necessarily to measure the performance of an entire technological innovation system, but to gain more knowledge of the emerging technologies, and to hopefully reveal aspects regarding the diffusion of these that may be useful for further development. The contextual conditions surrounding development of 2G biofuels is believed to be highly pertinent, and a case study approach is chosen in order to cover these (Yin, 2003).

2.2 Strengths and weaknesses of the research strategy

External validity is linked with whether a study's findings are generalizable beyond the immediate case study, and has been a major barrier in doing case studies (Yin, 2003). The basis of this thesis is a focus upon three firms and related technologies. However, as the label indicates, 2G biofuels have already been classified in terms of a certain type of technology. That is to say that the range of 2G biofuels currently being developed consists of similar technology, indicating that findings related to these technologies might be relative outside the context of the three represented firms. It is also worth noting that while part of a greater context, the emerging industry related to 2G biofuels in Norway is still very small in terms of key developers. The focus is here on gaining knowledge related to firm level innovation and diffusion.

Reliability of the case study is another aspect to consider. The concept of reliability is based on the idea that if another researcher followed the same procedure and conducted the same study, he or she would arrive and the same findings and conclusions (Yin, 2003). The goal reliability is thus to minimize errors and biases in a study (Ibid). In order to strengthen the reliability of this study, an outline of the thesis and interview guides were developed prior to data collection. The interviews were also taped and then transcribed in order to secure reliable transference.

Data collection leading to detailed description of 2G biofuel technology can however be challenging. This is particularly due to uncertainties related to the technologies; none of these companies have tested their technologies on a major scale. In addition, the competitive nature of the energy sector enhances the need for protecting the most complex nature of these technologies. These are firms trying to establish themselves within a competitive sector, and might prefer to protect technology that would give them any advantage against competing firms. I do not however believe that this is a great concern for this thesis, as minor details of the production process is significant when trying to reach a greater understanding of the emerging 2G biofuel industry through the represented firms.

2.3 Case Study preparation

In preparation for writing this thesis I have read numerous articles, documents and government reports. The subject of biofuels has been a much discussed topic and the number of related articles available both in written and online publications reflect this fact. One of my first challenges was therefore to get an overview of the current technology and the various actors. I quickly found out that this is an industry characterized by increasing globalization, and due to the limited amount of time and space available I decided to focus on Norwegian actors and technology, though a technological system is not limited by national borders. In order to gain a greater understanding of this industry I attended several seminars and conferences where I was able to speak to companies, policymakers and other representatives. At this stage I became increasingly interested in how this industry was able to emerge. Where were these new firms coming from, and how were they able to develop these modern technologies? These were some of my initial questions which later became the basis for developing formal research questions and research strategy.

2.4 Finding and choosing informants

I previously mentioned that there are relatively few key developers of 2G biofuels in Norway. It can however be challenging to get a complete overview of this industry as new actors and projects are created while others are abandoned within small time frames. With an emerging industry, networks may also be more informal and more difficult to identify. With my primary focus on the firm perspective, I needed to gain access to relevant actors within this area for indepth interviews. I decided to focus my search towards relatively new (and smaller) firms based on the assumption that these would be more easily accessible, and more importantly, less integrated with the fossil-based energy system.

I became aware of the existence of two of the firms represented in this thesis, Ecofuel and Xynergo, through a seminar held by the Norwegian biotechnology advisory board.[6] These were both emerging actors working with related technologies within the same area, but had very different strategies. Both firms agreed to be interviewed for this paper. The third company, Weyland, was brought to my attention through a news report, and while similar with the other firms in terms being recently established, they represented a different part of the industry through production of bioethanol, not synthetic biodiesel. Managing director Knut Helland agreed to be interviewed. All of the companies are in the process of developing their technologies and in the process of building facilities for testing and potential demonstration of technologies. These firms will be more closely presented towards the end of this chapter.

2.5 Semi-structured interviews

The informants were interview using ‘semi-structured’ interviews. This type of method facilitates a more fluid conversation, as opposed to a rigid line of predefined questions. An interview guide was prepared prior to the interviews in order to more easily follow the intended line of inquiry. I also tried to improvise and follow up on previous questions. In line with questions of validity and reliability, I attempted to pose the questions in the most unbiased

[6] The seminar took place on may 22. 2008 and was entitled ’Biofuel- Are we calculating our way into the sunset?”

manner possible. The research questions were central to developing key talking points for the interviews, but as the interviews progressed I sought to gain as much insight as possible into the firms and their technologies.

2.6 A presentation of key sources

This thesis is primarily based on information from three key informants. In addition to the interviews themselves, the firms have also provided me with business plans and other documentation. The firms' web pages have also been accessed frequently to follow developments and press releases issued by the companies. Other sources such as articles, research papers and governmental reports have also provided valuable information. Furthermore, interesting discussions with various industry representatives at seminars and conferences have also provided insight as well as new questions and inspiration.

2.6.1 The firms:

Ecofuel:

Ecofuel is a Norwegian company situated in Oslo. According to managing director Marcus Rolandsen the company was established in 2006 as a channel to make biodiesel available as an alternative to fossil fuels.[7] They later entered into cooperation with an unnamed Swedish firm which based on Fischer-Tropsch process had developed technology to produce a synthetic diesel based on natural gas (methane). They currently offer this synthetic diesel to their

[7] Interview conducted with Marcus Rolandsen, 6. June 2008.

partners in Norway, including Telenor ASA and Tine BA. This fuel is currently being produced in Sweden, but Ecofuel is developing facilities to produce the fuel in Norway. The firm is also working to develop the technology further. The company was represented by managing director Marcus Rolandsen and (then) head of research Gregoire Carl Truedsson for the interview.

Weyland A/S:

Weyland is a Norwegian company situated in Bergen. The corporate structure is based on a division between Weyland A/S and Weydahl & Helland A/S. The latter is organized as a parental company with the rights to patented technology employed by Weyland A/S. The firm has developed a process based on concentrated acid technology to produce bioethanol from cellulose based feedstock. Weyland aims to start up commercial activity based on projection, construction and sale of complete facilities for bioethanol production. They currently utilize a minor test facility, but are in process of completing a larger pilot facility in order to demonstrate the commercial viability of the technology. Weyland's process can potentially be used to convert a variety of feedstock into ethanol, such as industrial residues or agricultural waste. The interview was conducted with managing director Knut Helland at the firm's facilities outside of Bergen.

Xynergo A/S:

Xynergo was established in 2008 and is jointly owned by Norske Skogindustrier A/S, Viken Skog BA, Allskog BA, Mjøsen BA and Statskog SF. Xynergo is developing technology to produce synthetic biodiesel from woody biomass. The company is currently preparing to build a pilot-facility in order to test and develop their technology. They aim to have a larger production facility ready by 2015, capable of producing synthetic biodiesel equivalent to about 15 % of the current diesel usage in Norway. Despite being a relatively new company, Xynergo claim to have well-developed competencies through its affiliations with experienced actors within the paper production industry. The interview was conducted with managing director Klaus Schöffel at Norske Skog's offices outside of Oslo.

Note:

I will in the following refer to the companies simply as Weyland, Ecofuel, Xynergo, and also Norske Skog (which has close affiliations with Xynergo). I find this easier and more practical when referring to the companies without focus on the organizational structure or ownership.

Chapter 3

3.0 Technological introduction:

A natural starting point when focusing on firms developing 2G biofuels is to have a closer look at the technologies in question. In order to differentiate between different types of biofuels and related processes it is necessary to have a general understanding of these technologies. This chapter intends to provide an overview of existing biofuel technologies and to describe the technical characteristics and production processes associated with technologies of each represented firm.[8] As 2G biofuels are to a great extent based on existing knowledge, a simplified historical presentation is added to illustrate some linkages with previous developments. In order to adequately compare and describe maturation of biofuel technologies, processes related with first generation biofuels are also described briefly. Although there are several types of first generation biofuels, the most common types are bioethanol and biodiesel, and are therefore focused upon here. Technological development and innovation are fuelled by social processes such as knowledge transfer and processes of learning, and some of these social processes may become more visible when analyzing specific technologies and related social actors. While this chapter is primarily descriptive, it serves as an important basis for further analysis in chapter 5.

[8] 'Technical' here refers to the physical componentsof the technologies.

3.1 First generation biofuels:

Bioethanol:

Production of ethanol is based on fermentation of sugar. For production of ethanol for fuel purposes, the most prominent sources of sugar are from sugar canes or through enzymatic hydrolysis of starch from wheat or corn. Brazil and the USA are the world's largest producers of bioethanol and have based much of their production on these raw materials. These processes to extract sugar are well-known, but are also energy intensive and the basis for much of the controversy surrounding biofuels.

Biodiesel:

Biodiesel may be based on several types of raw material, while biodiesel based on rape (RME) is currently the most common type in Norway (and Europe).[9] The production of biodiesel is considered easier and less energy-intensive than production of bioethanol.[10] The basis for biodiesel production is generally fat or vegetable oil. The vegetable oil can be extracted from pressurizing seeds from rape or other plants. The further production process is a well-known chemical process called transesterification. The fat or oil is reacted with an alcohol with the presence of a catalyst. The result of this process is the separation of glycerine and methyl esters; the latter commonly known as biodiesel. The glycerine is considered to be a valuable by-product often used in pharmaceutical-, cosmetic- or tobacco industries.[11] The biodiesel is then rinsed, dried, and added additives before it can be used. Biodiesel is well-suited for mixing with

[9] Biodiesel made from rape is known as RME – Rape Methyl Ester.
[10] Nobio: " http://www.nobio.no/images/stories/Biodrivstoff%20ved%20Union.pdf".
[11] National Biodiesel Board: " http://www.biodiesel.org/resources/biodiesel_basics/".

fossil diesel, but to a lesser degree when used in pure form (100%) with modern diesel engines.[12] The diesel standard EN590 describes the physical characteristics that all automotive diesel fuel must meet if it is to be sold in the European Union, Iceland, Norway and Switzerland, and allows a mix of until 7 % biodiesel with petrochemical diesel.

3.2 Building on existing knowledge:

Technologies to produce 2G biofuels are in part based on well-known existing knowledge or processes. Technical obstacles combined with economic priorities or other factors of social nature have however limited industrialization of these technologies. The three companies analysed in this paper are currently developing technologies in order produce different types of bio-based fuel, and the ability to use and assimilate existing knowledge has been important for all companies in this process. The development of the Fischer-Tropsch process has been a central factor for development of technology to produce synthetic fuel, and is an important part of the technologies utilized by Xynergo and Ecofuel.

3.2.1 The Fischer-Tropsch process:

The Fischer-Tropsch process was developed by Franz Fischer and Hans Tropsch through their work at the Kaiser Wilhelm Institute and first patented in 1923.[13] This process has since been adjusted and developed in various ways, and the name is today used for a range of similar processes. The central function of the process is that synthesis gas through chemical reactions is

[12] This is linked with many factors, including the formation of nitrous oxides and strain on the diesel pump.
[13] Fischer-Tropsch Archive: (http://www.fischer-tropsch.org)

converted into various forms of hydrocarbons. For fuel purposes the chains of hydrocarbons are usually in liquid form. The most common resources used for feedstock have been coal and natural gas, while biomass more recently has been developed as an alternative. The technology was first used in large scale in Germany during the late nineteen twenties, where coal was used as feedstock in order to produce synthetic diesel.[14] While petrochemical diesel is produced through refinement of crude oil, synthetic diesel is “constructed” by hydrogen (H2) and carbon monoxide (CO) in the form of synthesis gas; thereby the label ‘synthetic’. The production of synthetic fuel roughly consists of three main processes; gasification of feedstock, purification of the synthesis gas, and production of hydrocarbons through a Fischer-Tropsch synthesis. Due to limited availability of petrochemical fuels, the technology became a partial solution to Germany’s energy needs during the Second World War (Becker, 1981). It was also in this period used by the Japanese.[15] The process of producing synthetic fuel from coal was expensive (and highly polluting, though not a consideration at the time) and following the end of the Second World War other sources of fuel were available. While the technology was abandoned on an industrial scale, research was continued both in Britain and The United States, where it was seen as an alternative to “foreign oil”. Especially in the United States, where there were considerable coal reserves, several unsuccessful attempts were made to revive the technology.[16] Increased availability of fossil fuels and high production costs are factors that are generally attributed to have complicated further industrialization of technology to produce fuel using the Fischer-Tropsch process. While the technology was not put to large-scale industrial

[14] “The Early days of Coal Research”, USDOE, (http://www.fe.doe.gov/aboutus/history/syntheticfuels_history.html)
[15] “The Early days of Coal Research”, USDOE, (http://www.fe.doe.gov/aboutus/history/syntheticfuels_history.html)
[16] Ibid

use, the basic processes were well-known. This would later prove important for further diffusion and development of the technology. During the apartheid years, South-Africa was subject to strict limitations as result of the international trade boycott, resulting in reduced availability of petrochemical fuels. In order to provide an alternative to imported fuels, Fischer-Tropsch technology was used extensively to produce synthetic fuels. Through many years of experience with this technology several improvements have been made, contributing to making the technology more cost-efficient. Though the boycott towards South-Africa has long since been lifted, the South-African oil company Sasol continues to produce a significant amount of the country's fuel based on gas using Fischer-Tropsch processes.[17]

The Fischer-Tropsch process has been utilized industrially on several occasions, despite negative aspects such as high costs, when there has been a lack of other alternatives. Through several years of development Sasol has been able to increase the efficiency of the process sufficiently to commercialize the technology on a long-term basis. Several actors, including other major oil companies such as Shell and StatoilHydro, have been working to commercialize technologies to produce synthetic diesel from natural gas. Technologies to produce synthetic fuel using gas as feedstock are commonly labelled as Gas to Liquids (GTL), where the Fischer-Tropsch process is an important factor. As a supplement to piped gas and liquefied natural gas, GTL technology has been considered a solution to exploit gas large reserves. GTL technology therefore represents a potential source of additional income for actors that have access to large natural resources.[18]

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[17] Sasol homepage, " http://www.sasol.com/sasol_internet/frontend/navigation.jsp?navid=600003&rootid=2"
[18] StatoilHydro homepage:
http://www.statoilhydro.com/en/TechnologyInnovation/gas/GasLiquidsGTL/Pages/KortOmGTL.aspx

3.3 GTL synthetic diesel - The Ecopar GTL:

Ecofuel is currently offering synthetic diesel based on GTL technology which has been developed and patented in Sweden.[19] Ecofuel has labelled the synthetic diesel 'Ecopar GTL', which at this time is being produced by their Swedish partner. It should be noted that as GTL synthetic diesel is based on natural gas, it should not be considered a renewable fuel. Compared with conventional diesel, the GTL diesel does have several environmental advantages, including significant reductions in carbon monoxide (CO) and nitrous oxides (NOx) emissions. While the end-product is biodegradable and toxin-free, the production process includes emissions of greenhouse gasses (though slightly lower than regular diesel). The development of the technology can be traced back several years and should be seen in connection with what was considered the main environmental challenges during this time. According to managing director of Ecofuel, Marcus Rolandsen, the technology can be directly linked with the implementation of the Gothenburg protocol, which was aimed at solving issues related to local pollution, not human-induced climate change.[20] The social climate at the time of initial development may have influenced the technological development; local pollution seems to have represented a greater challenge than global warming. Rolandsen characterizes the Ecopar GTL as a significant improvement compared with the fossil fuels, but not as a definite or final solution (Ecofuel interview). He argues that they have managed to solve several important challenges in the value chain, while striving for further improvement at earlier stages of production process, mainly addressed at developing solutions for handling and utilization of renewable feedstock sources

[19] The fuel and production processes are similar to that of the GTL produced by Sasol and others, but has also been subject to further development.
[20] Ecofuel interview. Shell homepage: "

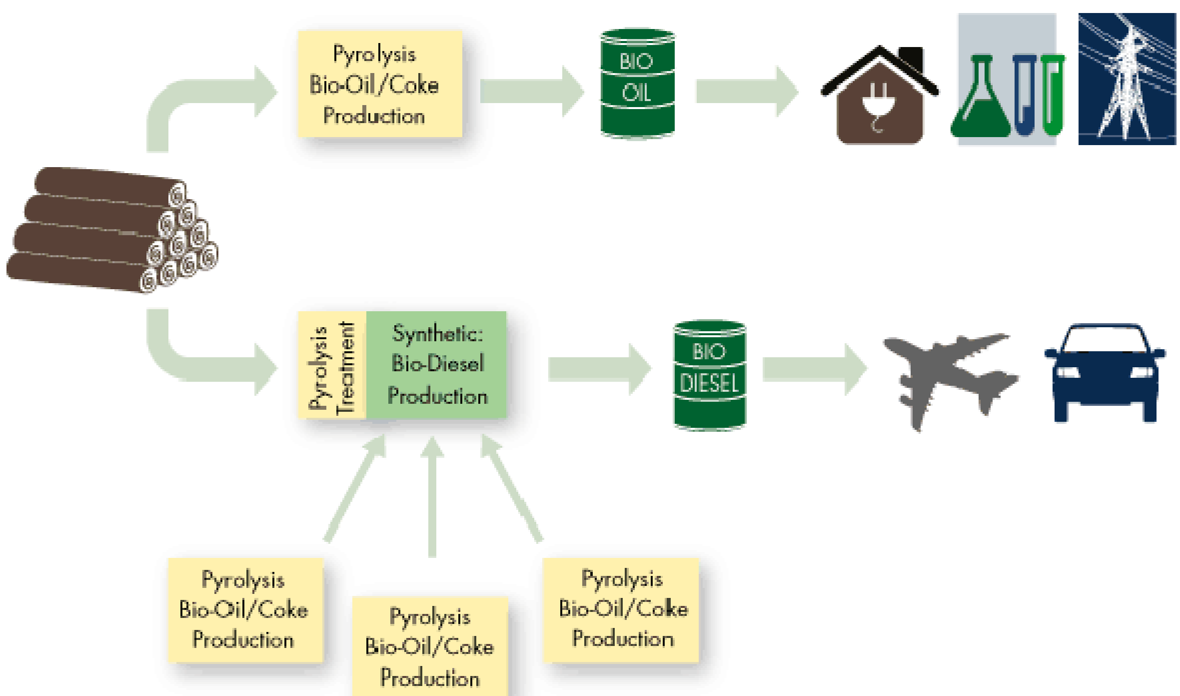
(Ibid). Ecopar GTL meets the requirements set for the European diesel standard EN590, and can be used in all diesel engines and can also be mixed with petrochemical diesel.

3.4 From gas to biomass:

An important distinction is made between 'synthetic diesel' and 'synthetic biodiesel'. The production processes to produce both synthetic diesel and synthetic biodiesel are similar, and consist of the same main processes: Gasification of feedstock, purification, and production of liquid hydrocarbons through Fischer-Tropsch synthesis. While production of synthetic diesel is based on coal (CTL) or gas (GTL), synthetic biodiesel is based on biomass; a process commonly known as Biomass to Liquids (BTL). The type of feedstock which is used represents the main basis for the distinction, and influences the further production process both through the technical characteristics of the feedstock and interlinked factors such as costs, energy intensiveness and environmental consequences.

3.5 Xynergo's technology – 'Xyn'-fuels:

Xynergo is developing technology to produce synthetic biofuel from woody biomass, which can be used to produce a range of products, most notably bio-crude oil and synthetic biodiesel. These are collectively labelled by the company as 'Xyn-' fuels. The Xyn-oil may be considered a substitute for regular heating oil, and is aimed at meeting demands within this area. The production of Xyn-oil may contribute to more effective utilization of resources through optimizing feedstock options for Xyn-diesel production (Xynergo interview). The synthetic biodiesel is however developed for fuel purposes, as a potential substitute for petrochemical diesel, and is therefore the product in focus. Technologies to produce synthetic biodiesel consist of numerous processes, such as the Fischer-Tropsch process. An important aspect of further development of the technology is to assemble existing knowledge and develop the production process to correspond with "new" feedstock types (Ibid). The process of converting biomass to synthetic fuel is dependent on type and characteristic of feedstock and several other factors. The graphics below is a simplified illustration of Xynergo's production process. It also illustrates that woody biomass may be converted into a variety of products, including synthetic biodiesel:[21]



[21] From Xynergo's homepage: www.xynergo.no/process

3.5.1 The Biomass to Liquid process:[22]

Although several challenges have to be solved before the technology can be operated on a commercial scale, it is possible to explain the basic principles of the production of the 'Xyn-diesel'. The process consists of six main process steps: The first part of the process is thermal pre-treatment of the feedstock, which is necessary in order to make gasification possible. The biomass is dried and then reduced into tiny particles. The feedstock is now prepared for the second part of the process; gasification. The tiny particles of dry woody biomass are exposed to severe heat in an atmosphere containing small amounts of oxygen. The low level of oxygen prevents the biomass from catching fire, and instead causes the release of carbon in the form of synthesis gas (CO and H2). The energy needed for this process is attained through combustion of biomass, which does include emissions of greenhouse gasses (CO2). At this stage of the process the synthesis gas contains several unwanted elements, including nitrogen, sulphur and carbon dioxide. The next step of the process is therefore to remove these unwanted elements through purification of the gas. After successful removal of these substances, the clean gas is then subject to a Fischer-Tropsch synthesis. During this process, the gas is through chemical reactions converted into long chain hydrocarbons in the form of wax. Large amounts of water are also formed during this process, which needs to be separated from organic contaminant before it can be released into the environment. In order to be used as fuels the waxes needs to be sized down and tuned to achieve necessary characteristics. Through distillation and a process known as 'hydrocracking', the waxes are converted into the desired synthetic 'Xyn-diesel'.

[22] This description is based on information gained through the interview with Xynergo, with additional information from Xynergo's homepage: www.xynergo.no.

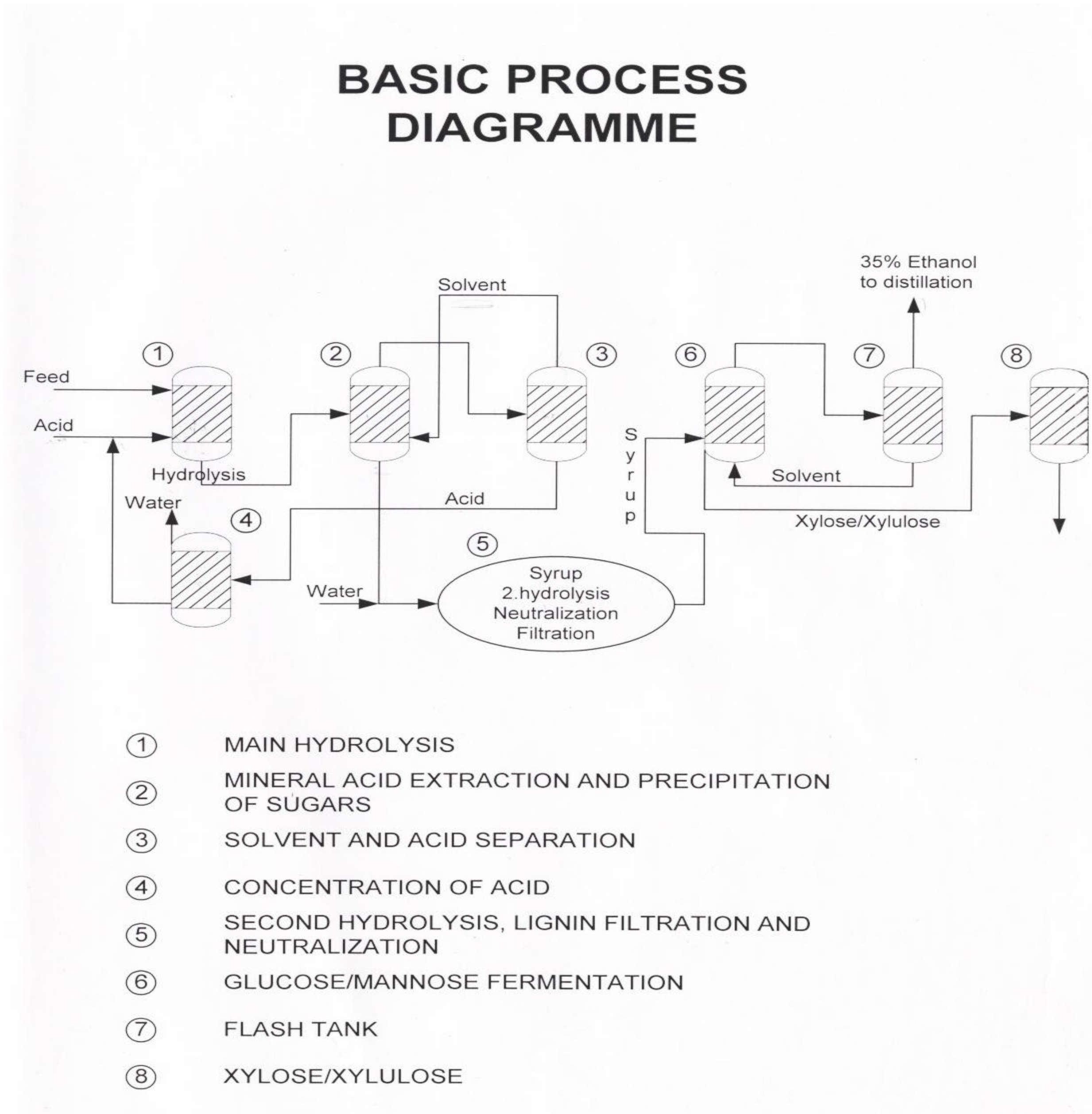
3.6 Weyland

Weyland has developed a process using concentrated acid to convert cellulose containing feedstock into bioethanol. Acid solutions are well-known catalysts often used in hydrolysis of cellulose.[23] Although these processes have been used frequently, they have previously not been employed to extract sugar from cellulose containing feedstock on an industrial level. This industrialization has according to Knut Helland been inhibited by several factors. A challenge when using concentrated acid processes has been the high consumption of acid, which has to be either recycled or neutralized (Weyland interview). Calcium carbonate can for example be used to neutralize acid, but will result in large amounts of gypsum as an unwanted waste product. As a result of high consumption of acid and occurrence of waste products, concentrated acid processes have traditionally been considered unprofitable (Ibid). Weyland has developed a method for recycling about 98,5 % acid, thereby providing a solution for a well-known bottleneck towards making the concentrated acid process economically viable. It is important to note that new challenges continue to arise, and continuous processes to develop and improve technology are necessary both for initial and continued commercialization. The following is a simplified description of the Weyland process:[24]

[23] Hydrolysis is a chemical decomposition in which a compound is split into other compounds by reacting with water.

[24] This description is mainly based on how it was presented to potential investors in the company's business plan of 2002.

3.6.1 The Weyland process:



The diagram illustrates the main stages of the production process. Since the process is performed continuously I have labelled different stages of the process to comply with the numbers associated with each container.

The first part of the process is the main hydrolysis, where the concentrated acid is mixed with the feedstock. The feedstock has at this point been grinded into small particles. The acid solution is a mix of sulphuric acid, phosphoric acid and water. It is advantageous to perform the hydrolysis continuously, and as the mass will gradually change from paste to fluid with unsolved lignin, it may then be pumped. The fluid is moved on to the second part of the process, where mineral acid is extracted and sugars precipitated. After mixing the fluid with an organic solvent, most of the sugars will be separated with unsolved lignin. The greater part of the mineral acid is combined with the solvent and moved on for recycling. This fluid will include some sugar remains which are also regenerated with the acid. It is the extraction in this second stage of the process which represents the most unique factor in Weyland's process. Acid and solvent are recycled in the third stage of the process. Recycling of the solvent occurs through distillation with reduced pressure and sufficiently low temperature, in order not to break down the remaining sugar in the acid. The solvent is evaporated and condensed while the acid (with sugar remains) is precipitated and prepared for re-use. The water is evaporated from the acid in the fourth stage of the process, and the concentrated acid is again ready to be added with the feedstock in the main hydrolysis. The sugar syrup goes through a second hydrolysis process in the fifth part of the process. Unsolved lignin is filtered out, washed and filtered again in order to prevent loss of sugar solution. Water is then added to the syrup which goes through a second hydrolysis and is warmed up to temperatures around 120 °C. The temperature is maintained for approximately two hours, sufficient to split oligosaccharide into monosaccharide. The sugar solution will contain a small amount of acid residue, which is neutralized using calcium carbonate. The resulting gypsum in addition to carbon dioxide (Co2) from fermentation, constitute the waste products from the process. Gypsum is separated through filtration, after which the solution is evaporated into a near saturated sugar solution. Glucose/mannose fermentation takes place in phase six. Concentrated sugar solution is added continuously to a bioreactor where immobilized yeast is used for fermentation. The same amount of ethanol malt is continuously removed from the bioreactor using an appropriate solvent. Regeneration of the solvent occurs in phase seven where ethanol is evaporated, while the solvent is recycled to the bioreactor. The resulting condensate constitutes the raw material for continuous distillation into the necessary purity (96 %). The fermentation of pentose is the final stage of the process, and takes place in container eight. Pentose is a monosaccharide containing five carbon atoms, such as Xylose, also known as "wood sugar". The fermentation of these types of sugars may be challenging, but can be converted into ethanol using gene-modified yeast. The pentose is extracted from the bioreactor (phase six) in order to prevent it from accumulating. The amount of pentose is dependent on the type and characteristics of the material (feedstock) used in the process. Weyland estimate that this technology has the potential to reduce the emissions of greenhouse gasses by 90% compared with fossil fuels.

3.7 Summing up technologies

This chapter has focused extensively on technologies and production processes and thus a summation and some comments on key aspects might be useful. The Fischer-Tropsch process is central to the technologies employed by Ecofuel and Xynergo, and the history of this process indicate how social factors may influence development and diffusion of technology. A basis for development of all the technologies described above is a focus on increased environmental awareness, and especially the reduction of greenhouse gases. This influences what is expected of the technologies from a range of perspectives; including consumers and policy makers, as well as how the firms consider commercial viability. How the technologies might affect the environment in a lifecycle perspective thus continues to be an important consideration during development. The distinction between 'synthetic diesel' and 'synthetic biodiesel' is important as it points to the type of feedstock that has been used for the production of the fuel, thereby influencing the characteristic of the fuel in an environmental perspective. However, the end product of both processes is practically identical. This is specifically linked with technologies being employed/developed by Ecofuel and Xynergo, who are both seeking to produce synthetic biodiesel, but have different strategies to reach this development.[25] Weyland's process is also based on well-known processes, but the firm has managed to solve what has hitherto been an important bottleneck towards commercialization. There are however several other challenges to production of bioethanol from woody biomass that can be directly linked with the production process such as fermentation of pentose and the transference from small scale to larger production facilities. The reliability of the technologies must also be proven, which, along with several other barriers to commercialization, will be discussed in chapter 5.

[25] This issue will be further discussed in chapter 5.

Chapter 4

4.0 Analytical framework

The purpose of this chapter is to present key literature related to the field of innovation studies. This will also provide theoretical framework in order to contextualize and analyze findings.

4.1 Innovation and economic growth

The drivers of economic growth have been much discussed in the past, but there is now a broad understanding that innovation is a central to economic growth (see e.g. Edquist et al., 2001). Joseph Schumpeter (1883 – 1950) was one of the first to focus on the role of innovation in economic and social change (Fagerberg, 2005) According to Schumpeter, economic development has to *"…be seen as a process of qualitative change, driven by innovation, taking place in historical time*" (Ibid). Qualitative here indicates an improvement or progress, while historical time here points to a continuous process. He also suggested a systemic approach, focusing on the co-evolution of technology, organizations and institutions. According to Jan Fagerberg, Schumpeter tried *"…to develop an understanding of how innovation, explained as a social phenomenon, shaped economic evolution"* (Fagerberg, 2002). The prevalent neoclassical economic theories at the time focused on capital accumulation, while Schumpeter saw innovations a driving force, understood as new combinations of existing knowledge. He labelled the activity of combining knowledge in new ways as the "entrepreneurial function", and focused especially on the role of firms as he considered innovation as a social function in an economic sphere; with a commercial purpose (Fagerberg, 2002). Schumpeter had a perspective on industries as evolving (in circles) from birth through maturity and death, where new products and processes would replace old ones; which is essentially what Schumpeter called the process of creative destruction (Nygaard, 2008). Based on Schumpeter's ideas on business cycles the important role of technology and institutions is recognized within the field of evolutionary economics and the evolutionary perspective on economical development (Ibid).

It may at this point be fruitful to illustrate the concepts of 'invention' versus 'innovation'. Jan Fagerberg describes invention as the first occurrence of an idea or a process, while innovation being the attempt to carry it out in practise (Ibid). While an invention may be more easily carried out, a combination of different types of knowledge, capabilities, skills or resources is usually needed in order to commercialize the idea; or to turn an invention into an innovation. He further notes that the two concepts may be closely linked, but also that there in many cases is a considerable time lag between the two (Ibid). Fagerberg describes several possible factors that may contribute to long lags from invention to innovation, stating that *"…some or all of the conditions for commercialization may be lacking"* and further suggesting that *"There may not be sufficient need (yet!), or it may be impossible to produce and/or market because some vital inputs or complementary factors are not (yet!) available"* (Fagerberg, 2005). A combination of these suggestions is central in the cases of the represented technologies**.** The most easily identifiable challenge is that the technologies are not yet fully developed, though each of the firms' technology has reached different level of maturation. Acquiring necessary knowledge, competencies and resources is central both in order to develop technology and in the work towards successful commercialization.

4.2 Perspectives on innovation:

The literature on innovation systems can be closely linked with the systemic flavour of Schumpeter's broad evolutionary perspective (Clausen, 2007). But contrary to evolutionary economics, innovation system perspectives are not economic theories, but concepts that integrate theoretical perspectives and empirical insights based on decades of research (Lundvall and Borras, 2005). Systemic theories of innovation offer a different perspective than traditional linear models. The linear view of innovation processes may be understood as *"…science leads to technology and technology satisfies market needs"* (Gibbons M et al., in Edquist and Hommen, 1999). These models do not include feedback in the different stages of the innovation process and envisions a *"…uni-directional flow from basic scientific research to commercial applications"* (Edquist and Hommen, 99). Rosenberg and Kline (1986) have pointed out that without focusing on feedback and trials within innovation processes one is also disregarding learning processes crucial to innovation. Systemic theories on the other hand, focus on the potential complexity and interactions between different elements of the innovation process. Based on systemic models of innovation, several systems of innovation approaches have been developed. These are not formalized theories, but rather frameworks in order to better understand innovation processes. Charles Edquist (1997) has identified some main characteristics of systemic approaches where innovation and learning processes are placed at the centre of focus. Innovation is here understood as producing new knowledge or combining existing knowledge in new ways; making innovation essentially a process of learning. Systemic perspectives are both holistic and interdisciplinary, and include economic, organizational, social and political factors. Edquist also emphasize the historical perspective; innovation processes are characterized by developments and feedback processes that develop over time. Edquist argues that the best way of studying innovation processes is therefore in terms of *"…the co-evolution of knowledge, innovation, organizations and institutions"* (Edquist and Hommen, 1999). Organizations are formal structures like research institutions or firms, while institutions can be understood as informal structures like laws, rules, regulations or cultural habits, and are considered central in order to understand the social patterning of innovative behaviour (Edquist and Hommen, 1999). The often complex relations between organizations and institutions are the basis of the systemic emphasis on interdependence and non-linearity; that not only the elements of the system determine innovation, but also the relations between them (Ibid). There are several versions of innovation systems approach, which are often based on definitions of the limits for the innovation system, and depending on the focus of research.[26] Tommy Clausen points out that there are important similarities between different versions of the system perspective: All versions emphasize the understanding of the innovation system as a knowledge environment where firms and organizations interact and learn from each other (Clausen, 2007). Innovation is all cases seen as a cumulative process that is both path- and context-dependent (Lundvall and Borras, 2005).

Several scholars have pointed out how technology is influenced by social aspects such as cultural habits, religion or policies (see eg. Mokyr 1992 or Bijker & Pinch, 1987). In their influential article *The social construction of facts and artifacts* (1987), Bijker & Pinch explore the development of the bicycle, and illustrate how different social groups interpreted this artefact

[26] Common examples are national-, sectoral- or technological innovation systems (see e.g. Lundvall et al., 2002, Malerba, 2005 or Edquist, 2005)

in various ways. Different interpretations are here shown to have shaped the development of the bicycle through what might be referred to as feedback processes. When a design is reached where relevant social groups consider problems with the artefact solved, the technology achieves "closure", which can be explained as the stabilization of an artefact, similar to the establishment of a dominant design (Bijker & Pinch, 1987). Advertising is mentioned as example of an instrument towards achieving closure through influencing how an artefact is interpreted by social groups. Bijker and Pinch have through their focus on the social construction of technology further illustrated the social nature of innovative activity. This has contributed to an emphasis on more holistic systemic perspectives, as alternatives to traditional (or neo-classical) linear models.

4.3 A technological innovation system

The focus on technological systems follows the same pattern as other systemic perspectives in that various agents and institutions must be seen as parts of a larger system in order to explain economic change. There may however be several technological systems in each country, thus differing from national innovation systems (Carlsson et al., 2002). In his article *The Evolution of Large Technological Systems*, Thomas Hughes (1993) studies the introduction of the electrical power system between 1870 and 1940. The systemic perspective is here used to illustrate that there were a number of complementary technologies and actors involved in the diffusion of electrical power. One of the functions Hughes here attempts to demonstrate is that society shapes technology and the paths of technological development. Technological systems are here understood being socially constructed and shaping society in a process of continuous change

(Ibid). Carlsson and Stankiewicz (1991) have also focused on technological innovation systems, suggesting it can be understood as:

"…a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology"

Following this understanding, 2G biofuels can be considered as a technological system. The boundaries for the system may however be unclear, depending on how we chose to see it. Do we consider it as apart of a bigger system consisting of all technologies related to transportation, or we may chose to look at engine technologies in a systemic perspective? In this case, the main point is to identify the main factors that influence development and diffusion of 2G biofuels, based on the perspective that it is not sufficient to simply consider the technical characteristics of technology, but also the many social processes involved. Bergek and colleagues also point out that the TIS is not limited only by the components that are exclusively dedicated to the technology, but all components that influence the innovation process for that technology (Bergek et al., 2008).

4.3.1 Identifying a system

The limits of the technological innovation system can sometimes be unclear, but a natural starting point when trying to identify actors related to the 2G biofuels technological system is to focus on who is involved in the value chain. It then becomes clear that the production process itself only amounts to a small part of a long process that includes procurement of feedstock, transportation and processing, in addition to other processes that eventually would lead to an end-product on the market in which consumers would constitute an important influence. By looking at the value chain together with information gained through the interviews, it is possible to identify some key actor within the TIS related to 2G biofuels. It is however important to stress that the following list is far from exhaustive, and only serves as an indication of the complexity of the system, not as a complete overview:

Firms (Key developers):

This includes both small firms and larger corporations that are involved in the development of technologies to produce 2G biofuels. Within the Norwegian context, and in addition to the firms represented here, Borregaard should be mentioned as they are developing technology similar to that of Xynergo.[27] In an international perspective, several actors are working to develop similar technologies, CHOREN industries being one example. In terms of GTL technology, Shell and Statoil should be mentioned.

Specialist firms:

These are firms that tend to specialize themselves within certain areas of the value chain. An example is firms who specialize in gene-modified yeast for the fermentation of pentose.[28]

Hardware manufacturers:

The firms do not construct the hardware necessary for production themselves, and companies that produce different types of hardware should also be included.

[27] See Borregaard homepage: “www.borregaard.no”
[28] See description of Weylands process for more information on pentose.

Universities and research organizations:

Several research organizations have been, and are, influential in the process of developing 2G biofuels. The exact contribution can however be difficult to measure, but there are some obvious direct linkages: Research organizations have been directly involved in the development of Weyland's technology, such as SINTEF and Bergen University College (BUC). In addition, The Norwegian University for Life Sciences (UMB) and Norwegian University for Science and Technology (NTNU) should be mentioned as important R&D contributors within this area.

Government and authorities:[29]

The authorities are an important of the technological system as providers of policies and framework, and may also include advisory organization such as the Norwegian Research council. Organizations such as Innovation Norway are also important and have for instance provided both Ecofuel and Weyland with financial support.

Non-governmental organizations (NGOs) and special-interest groups:

This category covers a range of various organizations representing different interests related to the development of 2G biofuels, and can potentially have great influence to the diffusion of 2G biofuels. This might be interest organizations such as NoBio (representing biofuels producers), Norwegian Automobile Association (NAF) or environmental organizations such as Zero, Greenpeace or Bellona.

[29] The role of policymakers will be discussed under the separate heading "policies" in chapter 5.

Investors:

This may be various actors that choose to invest or support firms developing technologies. Telenor ASA has for instance been an important partner for Ecofuel. Sarsia Seed is an example of an investment fund, based on public and private funding on an equal basis, which has provided Weyland with financial support**.** Both in terms of support and investment, as well as representing an interest themselves, investors may be influential actors.

Chapter 5

5.0 Analysis and findings

The most important feature of this chapter is to present and discuss the empirical data looking to provide answers to the initial research questions:

a) *What are the main characteristics of 2G biofuels?*

d) *How has organizations and institutions influenced development of the represented technologies?*

e) *What are considered the main challenges for diffusion and commercialization of 2G biofuels?*

The first question has been partly answered through the technical description in chapter three, but will be further analyzed here. The second question focuses on how various organizations and institutions have influenced development so far, and is naturally interlinked with processes towards commercialization. The third research question is focused on identifying main challenges that has to be overcome towards commercialization from the firms' perspective. The objective here is not necessarily to identify all barriers to diffusion and commercialization, but to gain more knowledge regarding the firms and processes that influence development and diffusion of 2G biofuels. I will in the following be using a broad understanding of the innovation system perspective, acknowledging the significance of learning processes and interaction between organizations and institutions as the basis for knowledge creation and innovation.

5.1 An organizational starting point

For organizational purposes, the successful introduction of new products, processes and practices into society can be seen as three main processes; invention (new idea), innovation (the idea in practice) and diffusion (implementation) (Hall, in Fagerberg et al., 2005)[30] Following Hall's rough model, the ideas behind the technologies (or processes in this case) can here be considered inventions, while innovation would be to turn these ideas into working processes on an industrial scale. Diffusion of these technologies is however crucial if they are to have any economic (or environmental) impact.

"…successful innovation requires a design that balances requirements of the new product and its manufacturing processes, the market needs, and the need to maintain an organization that can continue to support all these activities effectively" (Rosenberg and Kline, 1986).

The represented firms need to succeed with both the technical- and the social aspects of innovation when working towards commercializing their technologies. In neoclassical economic theory, firms were often considered to have perfect knowledge which in turn enabled them to optimize their behaviour (Carlsson & Stankiewicz, 1991). It is now widely recognized that firms operate with different knowledge bases, as well as under different assumptions regarding

[30] Hall acknowledges the limitations of this modell, but argues that it serves a useful organizing principle.

technology, markets and other areas (Ibid). During early stages of development firms develop a foundation for further progress, which may include establishing initial knowledge bases, developing networks, creating business strategies and developing technology. The following paragraphs will briefly present how the informants have described the establishment process behind each firm; giving an indication of the different "starting points" in terms of competencies and knowledge bases, and also indicate how they have worked to strengthen these areas during early stages.

5.1.1 Xynergo:

Xynergo was established in 2008 as a subsidiary company to Norske Skog, which is a global company specializing in production of newsprint and magazine paper, and has been a part of Norwegian industry since its initial establishment in 1962. In relation to the establishment of Xynergo, the company expressed that it is interested in continued focus on core business areas, and wishes to maintain the role of leading paper producer.[31] According to Klaus Schöffel, developments within several related areas, such as an increased number of digital publications, have contributed to limit the presumed growth potential within paper production, leading Norske Skog and its affiliates have sought new areas for potential growth (Xynergo interview). Norske Skog is looking to use the firm's competencies related to industrial experience and knowledge to develop new business opportunities related to existing production. This search can be considered one of the prime motivations behind the establishment of Xynergo. As an experienced actor, Norske Skog claim to have knowledge and competencies especially linked

[31] Norske Skog Homepage: http://www.norskeskog.com/About-us.aspx

with logistics, experience with bio-energy production for internal steam and power production, large-scale biomass processing and access to a global biomass supplier network.[32] The production of synthetic diesel from woody biomass is considered to potentially provide several synergy effects related to the existing paper production (Xynergo interview). While having industrial knowledge and experience, the firm is currently looking to attract persons with competencies within gasification technologies, sustainable forestry, process chemistry and related areas.

5.1.2 Weyland:

Established by Karl Weydahl and Knut Helland, Weyland aims to start up commercial activity based on projection, construction and sale of complete facilities for ethanol production. Karl Weydahl began initial research on acid processes and related technology at Bergen University College (BUC) in 1987. Together with Knut Helland, who started working at BUC in 1991, they were able to develop the basic scientific principles behind the Weyland's process. Through their positions at BUC, Weydahl and Helland were provided the platform to perform research within this area, which also provided valuable networks within research forums. Research organizations have been, and continue to be, involved in different phases of development of the firm and its technology. According to Helland, the firm *"...keeps close ties to Norwegian research environments".* The firm currently has formal collaboration with SINTEF related to fermentation of pentose, as well as other more informal ties.

[32] Xynergo homepage: www.xynergo.no

Since the early stages of establishment, Weyland has provided opportunities for students who wish to write bachelor papers on various subjects related to the firm and its technology. The areas of research have been related to various areas such as projection of pilot-facility, chemistry and electro automation. The students have thus added to the firm's competencies, as well as contributing knowledge through problem-solving and scientific research. This type of work is characterized by learning processes that include feedbacks and trials that have been important to turn the initial idea towards a commercially viable innovation. Involving students in development of technology has also provided the company with the opportunity to acquire skilled workers that are familiar with the company and its specific challenges as successful students have been offered positions at the company after taking part in research projects.[33]

5.1.3 Ecofuel:

The establishment of Ecofuel in 2006, can in great deal be attributed the entrepreneurial activity of few individuals, including Marcus Rolandsen and Gregoire Truedsson, now managing director and head of research respectively. Rolandsen and Truedsson both have economical educations, which they believe facilitated establishment and development particularly during early stages.[34] They later entered into a partnership with an unnamed Swedish firm, which provided access to the employed GTL-technology. Ecofuel has cooperated closely with Telenor ASA since early stages of establishment, and this relationship will be focused upon later.

[33] They currently had three former students employed when the interview was conducted.
[34] Ecofuel interview

5.2 Innovation and economization

Joseph Schumpeter defined innovation as "…*"new combinations" of existing resources",* and offered new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business as examples *(*Fagerberg, 2005*).* After looking closer at the main technical aspects of the production processes related to 2G biofuels, it becomes clear that while these technologies have yet to be commercialized, existing and well known techniques and processes are central aspects. In other words, it is more a question of combining and adapting existing knowledge, than to develop entirely new products and processes. This is also an integral part of the firms' strategies:

"Our philosophy is to use the technology that has already been developed, but we want to assemble and optimize it for woody biomass" (Klaus Schöffel – Xynergo)

Klaus Schöffel argues that it would be both time-consuming and expensive to develop new techniques and processes, and the focus is instead on as adapting existing processes to new types of raw material, as well as making them more effective. A crucial part of Weyland's process is for instance the recycling of acid, reducing both waste and costs. But even without the recycling of acid, it would still have been a "working technology", in the sense that the process could still be used to produce environmentally friendly fuel. Commercialization of technology is however not only dependent on the existence of what one might consider a working technology, it must also (from a firm's perspective) be considered commercially viable - profitable. The recycling of acid then becomes a central element towards commercialization of the technology. Processes to reduce costs along the entire value chain become critical; economization processes are considered central for successful commercialization. Reducing production costs must however also be considered in a more holistic perspective. This brings us back to Hughes (1993) and the significance of developments within complementary technological systems. Xynergo consider there to be a potential to reduce costs by developing technologies within related areas, such as within the procurement and transportation of feedstock. Transportation of feedstock is limited by volume, not weight, so if it is possible to increase denseness of biomass (i.e. make more compact) one would reduce logistic costs. Developments within complementary systems could thus be of importance for the production of 2G biofuels, and might also create further synergy effects. Reduced costs within certain areas may affect other parts of the value chain as well; cheaper transportation could facilitate bigger facilities and thus greater economies of scale in a long-term perspective**.** The technologies are currently in early stages of development and characterized by expensive low-scale production. Economization processes are crucial in order to make technologies commercially viable from the firms' perspective. Innovation and diffusion is however both an individual and a collective act, taking place within the realms of the innovation system which includes a number of variables.

Cost reducing processes can be seen as an important focus for all the represented firms as price is considered an important aspect to consider in a commercial perspective. Before the technologies can be introduced to any market however, they need to be validated in terms of reliability and durability (Nygaard, 2008). During early stages of technological development, Xynergo and Weyland have employed small-scale test-facilities as important instruments in the innovation process. In order to prove that the technology can be relied upon in an industrial setting however, the firms are now establishing larger "pilot-facilities" which should be focused upon:

5.2.1 Demonstration facilities

Demonstration facilities can be viewed as a way for firms to promote stability (Nygaard, 2008). Weyland is currently in the process of completing a pilot facility capable of producing about 30 000 liters of bioethanol. Knut Helland points out that the primary function of the facility will be to demonstrate the technology on a larger scale, but without commercial intentions:

"…the pilot facility will not have any commercial function… only demonstration" (Knut Helland – Weyland)

This is of course also linked with Weyland's strategy to sells complete facilities for bioethanol production. Xynergo are also looking to developing a pilot facility which is labeled *"semi-professional"*, and considered as an important step towards proving the reliability of the technology:

"…it will be an important part, to verify before making a large investment in a full scale facility" (Klaus Schöffel – Xynergo)

These demonstration facilities must not be confused with smaller test facilities, but are larger facilities that provide the opportunity to test the entire value chain. Demonstration projects can be seen as important instruments to overcoming doubts related to durability and reliability, and a step towards market introduction. Demonstration facilities can thus be considered as important tools to validate, and possibly also help legitimize technologies through successful demonstration. The firms consider successful demonstration of technology on a semi-industrial level central for further diffusion.

5.3 Diffusion

"The impact of the new technology on the economic system is determined by its diffusion" (Carlsson & Stankiewicz, 1991)

Diffusion can be understood as the process in which individuals and firms in a society/economy adapt a new technology or the replace an older technology with a newer (B. Hall in Fagerberg et al., 2005). Diffusion of new technology is characterized by a significant element of uncertainty because of initially unsolved technical and market problems and unknown responses by various agents (Carlsson & Stankiewicz, 1991). Through historical comparisons of several artifacts, Paul David has pointed out the time-lag from introduction to substantial market penetration, and further illustrates the path dependency of each innovation through technical, organizational or institutional interrelatedness (Carlsson & Stankiewicz, 1991). Several path-dependencies related to diffusion of 2G biofuels can be identified, particularly linked with the fossil-based energy system. One example can be seen in the relation between 2G biofuel and existing engine technologies. Because modern engines are generally designed for fossil fuels, biofuels must be adapted to these technologies. The constructed synthetic biodiesel is for instance almost identical to petrochemical diesel (without several unwanted elements), and its development and diffusion must be seen also in relation to interconnected technologies. Klaus Schöffel points out that:

"…the car industry wants and loves this type of fuel as it allows for further optimization of existing engine technologies" (Klaus Schöffel - Xynergo).

In an attempt to expand the debate on "barriers to diffusion" of carbon-saving technologies, G. C. Unruh has argued that *"...industrialized economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale"*, which inhibit diffusion of emerging energy technologies (Unruh, 2000). Without elaborating on Unruh's argument, it seems evident that diffusion of 2G biofuels is closely connected with the fossil-based energy system in terms of interconnected areas such as social institutions, technology and infrastructure.

5.3.1 Developing markets

"An early formation of markets is … at the heart of the formative stage."(Jacobsson & Bergek in Jacob et al., 2004)

In the formative phase, market formation is often associated with exploration of niche markets, where the technology is some aspect is considered superior (Ibid). Here, learning processes can take place, new customer preferences can be formed and price/performance of the technology may be improved (Ibid). In the case of Ecofuel, the introduction of a product can be seen as a tool for further development. Unlike Weyland and Xynergo, Ecofuel already provide a more environmentally friendly fuel (compared with fossil fuels) on the market; the Ecopar GTL. The firm has been able to develop a market for the Ecopar GTL through cooperation with other Norwegian firms and organizations, and currently has contracts to offer tanking solutions with Telenor ASA, Hafslund Infratek, Tine BA, The Per Gynt Farm and Royal Norwegian Yacht Club (KNS).[35] Bronwyn Hall points out that as learning- and feedback processes that may enhance the original innovation arise during the spread of a new technology; diffusion is also a natural part of the innovation process (B. Hall in Fagerberg et al., 2005).While the Ecopar GTL is based on natural gas, further diffusion of the Ecopar GTL is considered by the firm to be an important part of the process of developing BTL fuel, which is based on many of the same scientific principles. Interaction with users**,** routine activities and general experience can be considered as learning- and feedback processes which add to the firm's knowledge base. Other competencies, such as social networks and practical skills must also here be considered. Ecofuel is however also dependent on diffusion of Ecopar GTL in a financial perspective. The fuel is currently the firm's main product and thus also considered the main income generator.

[35] Ecofuel homepage: http://www.ecofuel.no/www/Om_ecofuel/Historie/

"Norske Skog is a global company, with a global perspective on the development of biofuels"

(Klaus Schöffel – Xynergo)

Klaus Schöffel explains that the Xynergo considers there to be a market for synthetic diesel in a global perspective. The close affiliations with Norske Skog may facilitate access to international markets, which is especially linked with access to greater feedstock resources. However, Schöffel stresses that the company will not build production facilities abroad until the technology has reached a higher level of maturation through successful demonstration in the demonstration facility. Weyland seeks to sell complete facilities for bioethanol production and aim their commercial potential towards the international market. Successful demonstration of the technology is thus considered crucial, which is why they also have a demonstration project in Taiwan. Research and development is here aimed at using other types of cellulose-containing feedstock, such as corncob or other waist products. Apart from an R&D project, demonstration projects abroad can here also be seen as a tool towards establishing markets.

5.4 The role of institutions

Jan Fagerberg has pointed out that firms do not normally innovate in isolation, but in collaboration and interdependence with other organizations and institutions (Fagerberg, 2005). The interrelated processes between organizations and institutions are in systemic theories on innovation considered central towards understanding innovational processes. A main focus on organizations will take place later in this chapter, while the role of institutions is focused upon here. Precisely how and to what degree various institutions influence development and diffusion of 2G biofuels is however difficult to say, as institutions ,understood as informal structures such as laws, rules, regulations or cultural habits, can be naturally integrated in various processes and hard to identify. Further diffusion may for example be linked with social acceptance of the technologies, which will become more visible when the technology has reached a semi-commercial level. But even at an early stage, Marcus Rolandsen stresses the need to clarify the environmental aspects of technologies through dialog, including the negative aspects (Ecofuel interview). This must be seen in relation to development of first generation biofuels, where diffusion was influenced by the controversies surrounding environmental issues. Openness and dialog is by Ecofuel also considered a way to influence social perspectives on GTL technology through explaining that while their fuel may not be a “perfect” solution, it is a step in the right direction (Ibid). Policies are another set of institutions that are considered to be highly influential to further development and diffusion of 2G biofuels. Although the effects of policies, or lack of policies, also may be hard to establish – some key perspectives may be considered.

5.4.1 Policies and institutional framework

Formation of markets, along with access to resources and legitimacy of a new technology and its actors, is closely connected with institutional framework (Jacobsson & Bergek, 2004). Policies may for instance influence stimulate markets and influence demands. There is however several types of policy instruments, which we can roughly divide into four main categories:[36]

[36] This paragraph is based on explanations by Myklebust, B.,.(2008).

Regulation – Policymakers can set limits to certain activities, such as prohibiting a certain substance, demand the use of a specific type of technology, setting limits or goals (e.g. related to emissions), or demand a certain design to be used – for example the use of catalyst in cars.

Government expenditure – Public funds are used specifically to invest in environmentally friendly projects, such building infrastructure or providing subsidies.

Voluntary action – Businesses or industries voluntarily engage in environmentally friendly activities (e.g. based on notions of corporate social responsibility).

Market based instruments (MBIs) – Often labelled as "the invisible hand"; these are a number of instruments based on the idea that businesses will act more environmentally friendly if it is to their benefit. MBIs are thus used to stimulate the market, through e.g. taxation, to create conditions where it's in the firms' interest to choose more environmental solutions.

Policies or economic framework may influence the firms in different ways, but effects can be difficult to measure. European regulations are for instance claimed to have affected how Weyland considered the market for their technology at an early stage. Knut Helland describes the European Union's goal to replace 20% of fossil fuels with alternative fuels by 2020, as *"...highly influential in creating markets for our technology"* (Weyland interview). In this instance, the regulation can be seen as having a direct effect as it influenced the firm's view on market opportunities.

Similarities with fossil fuels and shared infrastructure may cause 2G biofuels to be subject to competition and comparison with regular petrochemical fuels. In addition to a number of factors such as public acceptance and markets, price is of importance in order to be competitive with fossil fuels on a commercial level. Economization processes are therefore important to contribute to lower production costs and resulting prices. In addition to factors that are directly linked with the production process, policies can be influential in determining price and profitability. Policies towards taxation of alternative fuels can for example be seen an influence on diffusion of Ecofuel's Ecopar GTL. Since the Ecopar GTL is produced from a fossil fuel resource, it has been subject to the same taxation as regular fossil fuels, despite environmental benefits. This can be linked with a shift of focus in politics, and more directly to the Gothenburg protocol. This is an international protocol ratified by Norway, in which Norway agreed to reduce emissions of $SO_{2,}$ NO_X as well as some other components (SSB, 2005). Common for all these substances is that they are primarily related to local pollution, which was a significant challenge at the time. (It is worth noting that there have been considerable reductions in national emissions of NO_X in recent years – perhaps the protocol has had an effect?) The point here is that the Ecopar GTL represents significant reductions in local pollution compared with fossil fuels (and especially diesel). But the social-, and thus the political, agenda seems to have shifted, and there is no longer a strong political focus on these environmental challenges (at least not policy wise). According to Marcus Rolandsen, policy-makers have struggled to develop policies that are adapted to new types of alternative fuel, which has complicated the financial conditions and thereby been a challenge for the firm (Ecofuel interview).

Policies, or lack of policies, may represent several challenges for diffusion of 2G biofuels. Several scholars, (see e.g. Lundvall and Borras 2005) have pointed out the need for innovation policy to take into account the broader social framework. One challenge related with policies and 2G biofuels is connected with differentiation. Xynergo argue the need for some type certification of biofuels in order to classify different types of fuels, for example according to emissions reductions (Xynergo interview). Bearing in mind that biofuels have been subject to much controversy, it is understandable that producers of fuel with low CO_2 emissions, such as 2G biofuels, would want to label their product as more environmentally friendly, especially with regards to commercialization and marketing. Another policy issue is related to sustainable forestry and the procurement of raw material. Klaus Schöffel points out that while Norwegian forests are certified according to certain standards (e.g. FSC), these do not include issues related to nutritions, which are considered influential to forests regenerative ability (Xynergo interview). He stresses that in order to maintain sustainable forestry also in a scenario where there is competition for feedstock, one needs to have sufficient knowledge in this area, in addition to policies where these challenges are included (Ibid).

Policies have also been used to actively promote diffusion of biofuels. The practise of substituting fossil fuel with a certain percentage biofuel has previously been emphasized as an important way to reduce environmental consequences by both Norwegian and European authorities. The European Union decided in 2003 that member states must ensure that the minimum share of biofuels sold is 2% by 2005, increasing to 5,75% by the end of 2010.[37] The

[37] Directive 2003/30/EC of the European Parliament (http://europa.eu/scadplus/leg/en/lvb/l21061.htm)

Norwegian Pollution Control Authority (NPCA) suggested in 2006 that fossil fuels should contain an obligatory 2% biofuel by 2007, which was suggested increased to 4% by the year 2010.[38] Though it is generally estimated that this practise has aided diffusion of first generation biofuels, it has also been subject to controversy, and it is unsure how it will be practiced in the years to come. An important basis for developing Norwegian policies is the Kyoto protocol, which limits Norwegian emissions of climate gases between 2008 and 2012 to 101 % of 1990 emissions. In addition, as a result of the ”climate agreement” between various parties in the Norwegian parliament, Norway shall increase Kyoto obligations by 10 %. This type of regulation may help stimulate markets and create demand, but is not necessarily enough to stimulate innovation. There are many interests related to development of alternative energy technologies, as well as related to 2G biofuels. Several examples of policy challenges mentioned in the interviews focuses on specialized areas, and it should be expected that a similar adaptation of policies is appropriate. Developing policies that stimulate innovation and diffusion of green technologies can be considered a challenge for both firms trying to commercialize technologies, and for a society in need of environmentally friendly solutions.

5.5 Partners and cooperation

Following the notion that firms do not innovate in isolation, it may be useful to focus on some of the organizations that have been influential, either directly or indirectly, to development of the represented technologies. There are many types of collaboration, and may take place on several levels and be of informal or formal nature. Informal networks may certainly be of importance, but also difficult to identify. It is safe to assume however, that formal collaboration on many occasions also entails the creation of informal networks. In order to better identify linkages and the roles of organizations, there is here also a focus on how the firms have acquired financial resources and the significance of these contributions. In the case of these firms, financial support is also frequently interlinked with other forms of cooperation. For all the firms represented here, it can be established that cooperation with other organizations has been of importance. The complex nature of innovation, along with limited available data material, makes it difficult to identify the role of organizations on all levels, but some key developments related to the represented firms and technologies are focused upon here.

Through what is described as a long process, Ecofuel has established a close relation with Telenor ASA, a major firm specializing in telecommunications (Ecofuel interview). Marcus Rolandsen describes Telenor as an important partner for the company, from which they have also received financial support. This is argued to have been of particular importance during the formative stage characterized by high level of uncertainty:

"With a new product at such an early stage, one is dependent on assistance from someone that can really get you started" (Marcus Rolandsen - Ecofuel)

In addition to financial contributions, Rolandsen notes that Ecofuel has benefitted from Telenor's competencies in other areas, including involvement in shaping business plans and projects. As a private actor with much experience related to marketing and commercialization of products, Telenor may have fulfilled an important role towards commercialization, in which public organizations may have less emphasis:

"We were more challenged on our marketing- and product ideas by commercial actors than by the other organizations around us" (Marcus Rolandsen - Ecofuel)

Telenor can thus be said to have had an influential role as a knowledge provider and experienced actor, making contributions within areas where Ecofuel may not have had sufficient competencies at an early stage. Ecofuel's other prominent partner is an unnamed Swedish firm, which must be considered crucial to establishment of Ecofuel as the main provider of technology. There is however little additional information regarding the nature of this partnership, and is thus difficult to assess. Ecofuel has also received financial support from Innovation Norway.

Similarly to Ecofuel and Telenor, Weyland has also had a close connection with a major actor; Fana Stein & Gjenvinning A/S (FSG). FSG is a company specializing in waste management and recycling of metal. The company has primarily played the role of major investor, but has also provided office- and industrial facilities for Weyland.

"…the resources that support it (innovation) must be committed until the process is complete" (Sullivan in Fagerberg et al. 2005)

While also a knowledge provider through several years of experience within related business areas, the role of FSG as a long-time investor is here considered to be of great significance. Investments and financial support have been crucial for the Weyland's establishment and technological development, and will continue to be so until the technology proves commercially viable (which obviously is of importance for all the firms). In addition to investments from FSG, Weyland has received 5.4 million NOK from the Norwegian research council. The company has also received an undisclosed amount from Sarsia Seed, a Norwegian capital investment fund which focuses on supporting companies within the energy- and life sciences sectors. The investment fund is in turn financed through public and private investors on an equal basis.[39] The combination of private and public funding has provided Weyland with financial resources. In connection with development of a pilot facility, Weyland will also seek further grants from public sources, such as the research council (Weyland interview). When focusing on organizations, I must in Weyland's case also point out the previously mentioned connections with research organizations. This has been of importance to provide conditions for establishing the firm, scientific research and continued cooperation related to technological challenges. In addition, cooperation with companies that specialize on specific areas of the value chain is also important in order to acquire the necessary raw materials for production, such as acid or gene-modified yeast in Weyland's case. Cooperation with external technology providers is also important as the firms are developing pilot-facilities and are dependent on cooperation with other actors within this area as well. When searching for the desired competences, the firms

[39] See Sarsia Seed homepage for more information: www.sarsiaseed.com

search within a global perspective, so collaboration is not necessarily restricted with the Norwegian national system. Xynergo has for instance cooperated with CHOREN industries on developing gasification technology. Xynergo has also had access to experienced actors with industrial knowledge through its affiliations with Norske Skog and other owners. This relationship is also important in the continued technological development, including cooperation regarding harvesting methods and procurement of feedstock.

Major actors have played an important role for all three companies, and must be considered influential organizations through providing experience, financial support and social- and industrial knowledge. Cooperation with other organizations, including authorities, is also considered crucial for further developments. The need for cooperation can also be linked with the level of competences the firms have in various parts of the value chain. This might change over time, and during different stages of development. When moving from a small-scale production towards commercial sale of complete facilities for example, Weyland aim to use external firms for future projection and production of facilities.

5.6 Looking towards commercialization

The firms are currently on different stages of commercial development, and this is illustrated through the type of challenges they are currently facing. Ecofuel is the only company currently offering fuel on the Norwegian market. Weyland and Xynergo are currently only producing fuel on a minor scale in order to test and develop the technology. They are both however, in the process of building larger demonstration facilities. This must be considered a crucial step towards commercialization, and in order to answer questions regarding the reliability of the technologies. Performance improvements, cost reductions and establishing distribution networks are other important challenges in moving from a pre-production phase towards an establishing phase. These phases are not separate, but should be understood as a sliding transition with new layers of knowledge continually being added (Wicken, 2007). Improving the price/performance ratio must also be considered a challenge for commercialization, but this is also dependent on several factors outside of the production process. While the significance of policies and social acceptance have already been mentioned, developing economies of scale is considered crucial. Low-scale production is costly, and larger facilities, effective transportation methods and large stable markets are important to create a positive financial framework. In many ways, diffusion is fuelled by diffusion.

5.7 Summing up

Technologies to produce 2G biofuels (represented through the technologies focused upon here) can be characterized as complex processes in which existing knowledge such as the Fischer-Tropsch process or concentrated acid processes are central. As central elements of technologies to produce 2G biofuels consists of existing knowledge and processes, innovation in this area is largely focused on assembling and optimizing existing processes in order to develop a complete production chain based on renewable feedstock. Another focus of innovation is to develop technologies in related areas which may contribute to lower production costs when considering the entire value chain. The firms have been (and still are) dependent on support from, and cooperation with, major actors within the Norwegian system. While Xynergo is a subsidiary company to Norske Skog, FSG and Telenor have been crucial partners for Weyland and Ecofuel, respectively. Continued investment and financial support is considered to be of significance during the crucial development from low-scale to large-scale productions. These collaborations have not been limited only to financial support, but also been important in terms of providing industrial knowledge. Close connections with Norwegian research organisations have also been of importance, but as these networks often are more informal it is difficult to estimate the impact these have had. Research organizations can however be closely linked with the establishment of Weyland. Also, cooperation with SINTEF and NTNU can be directly linked with research on the fermentation of pentose. An important part of Weyland's process is the versatility in terms of feedstock, and solving challenges related to pentose might thus prove significant. Technological development is to great extent based cooperation with research organizations and in-house R&D, where test- facilities constitute a significant element. When acquiring knowledge related to technological challenges or specific areas of the value chain, the knowledge search is aimed towards a global perspective. When moving from pre-production towards an establishing phase demonstration facilities are of importance to prove reliability, which in turn can influence future conditions, as well as attracting buyers. The firms have also been dependent on support from governmental organizations, such as Innovation Norway and the Norwegian research council. The firms offer different products, and have different strategies in order to successfully commercialize their technologies. Creating markets is a central part of these strategies, and the firms have reached different levels of technological maturation and commercialization.

In terms of institutions, political framework can be identified as having a significant influence on the development of these technologies. European targets for emission reductions can for example be attributed to have influenced Weyland in their estimate on potential markets. The lack of policies or uncertain policies might also influence development of technologies in several ways. One example has to do with the differentiation of various types of biofuels. Firms that successfully produce (more) environmentally friendly fuel are looking for a type of certification in order to be differentiated from other fuels, thus potentially having an advantage in the market. Uncertain policy frameworks are considered central challenges for further diffusion of 2G biofuels. The continually evolving energy-sector may also influence commercialization through the emergence of other technologies.

Chapter 6

6.0 Conclusions

Global climate change and increased environmental awareness have contributed to increased demand for green energy. Within the transportation sector particularly, there is a need for alternative solutions to fossil-based fuels in order to reduce emissions, while also considering the possible end of fossil-fuels. The expectations to such solutions are high however, as it is expected that in order to be commercially successful the new technology must entail a significant environmental improvement, while also providing the advantages of fossil fuels.[40] Second generation biofuels are among very few technologies that are considered as a potential solution to challenges within the transport sector. These developments constitute an important background for this thesis. Three firms that are in the process of developing and commercializing 2G biofuels have been focused upon, along with their represented technologies. Important objectives have been to an increased understanding of 2G biofuels, gain more knowledge regarding the development process of the technologies, including the various major influences on this process, understood as organizations and institutions. In addition, I have focused on what is considered central challenges to further diffusion of 2G biofuels. The research further emphasizes the complex nature of innovative activity through highlighting the many factors that influence the potential success of the firms and their technologies. The low number of informants combined with qualitative interviews makes any general conclusion difficult. However, there are several findings that may add to the understanding of the firms and further diffusion of their technologies. One aspect is the close

[40] E.g. long range or a well-developed infrastructure.

relationship that these firms have with other actors within the Norwegian sector, including major commercial actors, research organizations and governmental organizations. In addition, central issues regarding policies have been mentioned which according to the firms has to be clarified in order to secure a stimulating environment. This is especially related to taxation of fuels, and in regards to sustainable forestry, including the procurement and availability of feedstock and nutritions. An important issue is also to gain more knowledge regarding sustainable forestry. Based on an experience of increased negativity regarding biofuels in general as a result of controversy related to 1G biofuels, Ecofuel and Xynergo also stress the importance of focusing on communicating both the positive and the negative aspects on their technologies. This may also be seen as a tool to influence the social climate, and to avoid possible controversies at a later stage.

6.0.1 Some ideas and finishing remarks

It is clear that commercialization of 2G biofuels is dependent on much more than simply the ability to manufacture fuel from biogas or woody biomass. Even after the technologies are proven reliable technically, several other factors influence further implementation. The existence and characteristics of competing technologies, how consumers react to the technology and level of taxation are just a few examples of issues that may shape diffusion. The development of 2G biofuels can also be seen as an incremental improvement within the realms of the transportation system; the cars, engine technologies and infrastructure will all remain fairly the same with the introduction of synthetic biofuels. Social developments related to the consumer society will thus have the potential to influence diffusion. Similarly, interests within the existing system will likely also contribute to processes that drive diffusion of 2G biofuels.

Considering the amount of raw material currently available in Norway, and although new technologies may emerge to change this amount, it seems unrealistic in any case that 2G biofuels can solve issues of emissions in the transport sector alone. A combination of technologies and social development is necessary if we are to achieve significant reductions. New ideas are thus obviously needed, both within micro and macro perspectives. There currently exist a number of advocacy coalitions linked with a range of different technologies, such as biofuels, wind-power, hydrogen or solar-power. In line with desires expressed by Ecofuel, one should perhaps focus on cooperation between all forms of alternative energies. Good ideas are not necessarily linked with one interest-group, and why would developers of say, hydrogen cars, go to a seminar on 2G biofuels? If all types are needed perhaps it is advantageous to focus on alternative energy, not wind, bio or solar? I believe this also is true from a policy perspective. In a sector characterized by uncertainty on several levels, it seems appropriate to encourage development of a broad range of alternative technologies. Technological development is both uncertain and time-consuming, and if the motivations for innovation is driven from an environmental perspective it seem appropriate to support a broad spectrum of technologies. History has shown that technology rarely appears “ready”, but needs time to shape and be shaped within a market environment. But if time is not on our side, policies would possibly be an influential instrument towards creating solutions sooner rather than later. However, paraphrasing Carlsson and collegues, the system’s long-term contribution on economic growth and sustainable development can only be assessed in retrospect (Carlsson et al., 2002)

6.1 Basis for further research

This thesis has focused on development and diffusion of 2G biofuels primarily based on data from three key developers. This has hopefully contributed to increased knowledge regarding these technologies and some of the challenges for further development and diffusion, including some central policy issues. In order to gain a more complete understanding however more research is needed. All areas of the technological system related to 2G biofuels can advantageously be studied in more detail in a holistic perspective. Some areas are considered particularly interesting, for example an increased focus on path-dependency and the role of large established actors within the energy sector related to diffusion of new energy technologies. Another interesting aspect that should be subject for further research is the development of policy frameworks that are designed to promote sustainable development. The energy sector is currently characterized by many entrants and heterogeneity in terms of technologies, operating in a rapidly changing environment. As this thesis has indicated, developing policy frameworks that is adapted to embrace all related areas can be challenging. Policies can be used as effective instruments towards stimulating continued innovation within the energy sector and more knowledge on how to use these instruments most effectively should be cherished. More knowledge on all processes related to development of new energy technologies will hopefully contribute to both increased economic growth and sustainable development.

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